

A Transmit Beamforming and Nulling Approach with Distributed Scheduling to Improve Cell Edge Throughput

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Abstract- Cell edge users in cellular deployment often suffer from low throughput due to interference from other base stations (BSs) or low received signal power at the mobile station (MS). Conventional methods like fractional frequency reuse (FFR) or transmit beamforming and nulling (BFaN) allocates the same amount of channel resources to serving cell edge users for all BSs in a semi-static way. It results in inefficient resource allocation due to BSs having different number of cell edge users and the numbers of cell edge users can change with time. Depending on whether the cell edge users are interference limited or SNR limited, different interference mitigation techniques should be used. Current solutions force the same interference mitigation techniques on all edge users. Our distributed adaptive resource allocation (DARA) scheme provides the interfaces and algorithm to solve the afore-mentioned problems. In addition, our DARA scheme beats the new WiMAX requirement of providing 22% increase in cell edge MS throughput while keeping the average cell throughput drop to be less than 5% when compared to the WiMAX baseline system.

Keywords- Beamforming; Nulling; Interference Mitigation; Spatial and Cross-tone Beamforming and Nulling; Advanced Antenna Systems

I. INTRODUCTION

This work is an extension of [6] to further improve cell edge user throughput rate. In a cellular deployment depicted in Figure 1, cell edge users have low SINR (signal to interference and noise ratio).

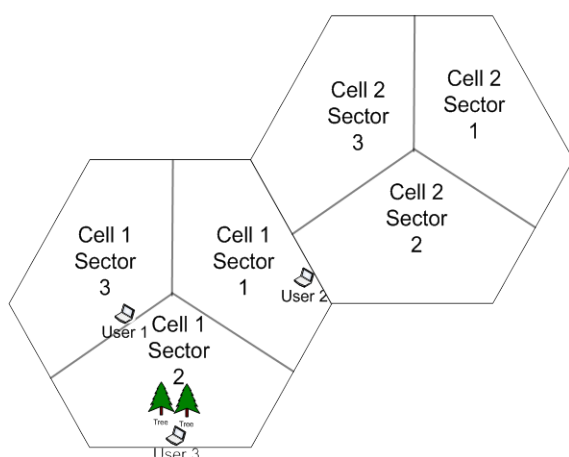


Fig. 1 A simple 2-cell cellular deployment

In the new IEEE 802.16 standard, a new baseline of 4x2 SU-MIMO is proposed. The old baseline is 2x2 STBC/SU-MIMO. Any new interference mitigation scheme compared to the new baseline must meet the following throughput improvement requirements:

- cell edge MS throughput must be increased by at least 10%;
- average cell throughput drop must be less than 5%.

There have been several approaches to solve this problem and there are two problems with these approaches. Proportional fair schedulers will allocate equal resources to all users averaged over a very long period of time. In the short run, edge users will typically have lower throughput rate. To solve this problem, techniques like transmit BFaN and FFR in current 802.16m standard advocate the idea of allocating a fixed fraction of channel resources to serving cell edge users for all cells. However, the problem is that each cell may have a different number of edge users as shown in Figure 2.

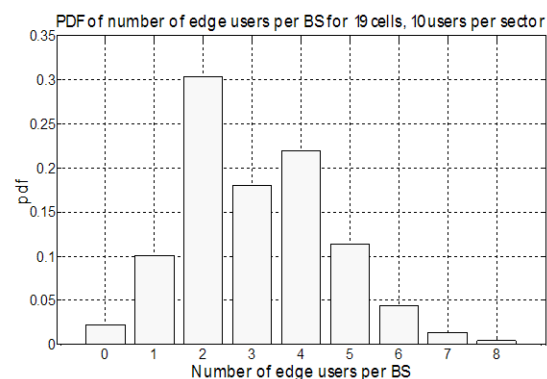


Fig. 2 Probability density function of number of cell edge users per BS

For a fixed resource allocation to serving cell edge users for all BSs, BSs with eight cell edge users out of ten users may be allocated too few resources while BSs with one cell edge user out of ten users may be allocated too much resource. In addition, the fraction of cell edge users per BS may change as well due to user mobility. To accommodate the changing number of cell edge users per BS over time, the current system performs the following. First, each BS must send its cell edge user information to a centralized RRM (radio resource management) unit. After receiving changes in the cell edge user number from all BSs, the RRM will provide a new resource allocation to all BSs. The BSs can then adopt this new allocation. This adaptation is centralized at the RRM. It does not scale well as the system grows in size and can be slow to respond to changes.

There are two types of cell edge users: interference limited and SNR limited. Interference limited edge users have high SNR but low SIR like User 1 in Figure 1. SNR limited edge users have low SNR like User 3 in Figure 1 that is far away from BSs. Both type of users need to have dedicated

resource allocated to them in order to guarantee some throughput rate. However, current interference mitigation techniques like FFR only helps interference limited users. Hence applying FFR to SNR limited users will lower their throughput rate since FFR uses only a fraction of channel resources to serving its users. On the other hand, for interference limited users, the throughput rate gain (due to SINR increase) generated by using an interference mitigation scheme should be greater than the throughput rate drop of using less channel resources associated with most interference mitigation schemes. Hence, interference mitigation techniques needed to be selectively applied to cell edge users in order to guarantee a throughput rate increase. For noise limited users, they should use the allocated edge resources and shall probably choose regular SU-MIMO. For interference limited users, they will use the allocated edge resources and shall choose the interference mitigation scheme that provides the highest throughput rate.

This paper studies the benefits of our DARA scheme and has made two key contributions. First, our DARA method will allow each individual BS to allocate resource to cell edge users according to the fraction of cell edge users they have. A parameter (multiplier) is provided to each BS to exchange the cell edge user throughput rate increase and the sector average throughput rate drop. This allows each BS to adjust the amount of resources it wants to allocate to serving its own cell edge users dynamically. Next, we provide a framework to allow each cell edge user to inform its serving BS whether it wants to enable interference mitigation schemes or not in its allocated resources and to choose which type of close-loop, open-loop interference mitigation schemes to use. Each cell edge user will choose a transmission scheme depending on whether it is interference-limited or SNR limited.

In this paper, we first provide a description of our proposed DARA scheme followed by simulation results and conclusions. We can see Reference [6] for a literature survey of interference mitigation techniques considered in IEEE 802.16m study group.

II. PROPOSED DARA SCHEME

Our DARA scheme can be carried out in 3 steps:

- cell edge MS identification;
- distribute resource allocation for cell edge users;
- MCS and interference mitigation scheme selection between each cell edge MS and BS pair.

Our DARA scheme provides two major advantages over previous interference mitigation schemes. First, it uses existing feedback and UL sounding mechanisms in existing IEEE 802.16 systems. Hence, this scheme can be implemented without additional standard changes. Second, no real time BS collaboration and real time information exchange over the backhaul network is required. Hence, system performance will be independent of the real time information exchange latency over the backhaul network.

A. Cell Edge MS Identification

Cell edge MSs are defined as MSs that have low SINR (\leq SINR threshold). Users that can receive signals from multiple BSs can measure the power level of the preambles transmitted by these BSs. IEEE 802.16e allows users to report their interference measurements to their serving BS for handover purposes. We will use these measurement reports

instead to determine whether a MS is a cell edge user or not at each BS.

B. Distributed Resource Allocation for Cell Edge MSs

For proportional fair type schedulers, the fraction of resource allocated to each MS in the long run is equal. Hence, we can allocate resources serving cell edge MSs to be proportional to the fraction of cell edge MSs present in each serving BS service area.

If a BS has $Q\%$ cell edge users, it will allocate each channel resource unit per frame to serving cell edge users only with probability ($Q\% \times \text{multiplier}$). The value of multiplier (≥ 1) is chosen to maximize the cell edge users throughput rate gain while keeping the average cell user throughput rate drop to be less than or equal to 5%. Next, each BS decides how much average cell user throughput drop, it can tolerate and set its multiplier value. In addition, each BS can set the value of the multiplier depending on the QoS needs of its cell edge MSs to enhance the user experience of these cell edge MSs in the short run to counter the effect of fading. On average, cell edge users will obtain $Q\% \times \text{multiplier}$ fraction of the total channel resources over time. All BSs use the same subcarrier allocation for channel resources per frame and they will try to line up the same scheduling quanta for serving cell edge users.

C. Cell Edge MS MCS and Interference Mitigation Mode Selection

MSs with low SNRs are noise limited. For noise limited MSs, interference mitigation schemes will only increase the SINR slightly and these MSs may be better served by boosting the BS DL transmit power. Cell edge MSs with low SIR and high SNR are interference limited. These edge MSs are better served by enabling the various interference mitigation schemes in [2], [3], [4], [5], and [6]. Each BS schedules its cell edge MSs over the allocated resources in a distributed fashion with no coordination with other BSs. Just as edge users choose their MCS (modulation and coding scheme), we propose to expand the scope and allow edge users to choose their MCS and interference mitigation schemes as well. First, an edge user will calculate its SINR with the various interference mitigation techniques and with SU-MIMO. Next, it will choose the interference mitigation mode or SU-MIMO MCS mode that will provide the highest throughput rate and will request its serving BS to use that mode. In the next section, we will show how this process is carried out.

1) MCS/Beamforming Scheme Decision by Cell Edge MSs:

In evaluating our DARA scheme, we use SU-MIMO as the baseline operation mode, spatial BFaN [6] or spatial and cross-tone BFaN as the two interference mitigation schemes for MSs to choose from. Other and more interference mitigation schemes can be used as well with our DARA scheme.

In spatial BFaN, the same signal is transmitted over multiple transmit antennas and received with multiple receive antennas. Beamforming weights are applied to these transmit/receive antennas which will form nulls and beam to reduce interference at undesirable locations and focus signals to desired users respectively. Using the same principle, the same signal is sent over multiple OFDM tones/subcarriers as well as over multiple antennas. Beamforming weights can now be applied across these multiple tones as well as multiple

antennas to form nulls and beams. If the same signal is sent over two tones, the link throughput rate will be cut in half. However, with the increased SINR, a more efficient MCS can be chosen so that the final throughput rate may still be higher than before. The relationship between the SINR with spatial and cross-tone BFaF and the SINR with spatial BFaF for equivalent data rates is derived as follows.

$$Rate_{\text{spatial_cross_tone}} = \frac{1}{2} B \cdot \log_2 (1 + SINR_{\text{spatial_cross_tone}})$$

$$Rate_{\text{spatial}} = B \cdot \log_2 (1 + SINR_{\text{spatial}}), B = \text{bandwidth}$$

$$Rate_{\text{spatial_cross_tone}} = Rate_{\text{spatial}} \Rightarrow$$

$$SINR_{\text{spatial_cross_tone}} = (1 + SINR_{\text{spatial}})^2 - 1$$

For instance, with spatial BFaF, we can only use QPSK $\frac{1}{2}$. With spatial and cross-tone BFaF, we may be able to use 64 QAM $\frac{1}{2}$. The final throughput rate using 64 QAM $\frac{1}{2}$ in this case is still higher than the throughput rate using QPSK $\frac{1}{2}$. However, changes like this are only possible for interference limited users. For SNR limited users, spatial and cross-tone BFaF can only increase its SINR by 3dB compared to spatial BFaF. According to Figure 3, an SINR increase of more than 3dB is needed for spatial and cross-tone BFaF to beat the data rate of spatial BFaF. Hence, SNR limited users may get higher throughput rate using spatial BFaF or baseline SU-MIMO mode.

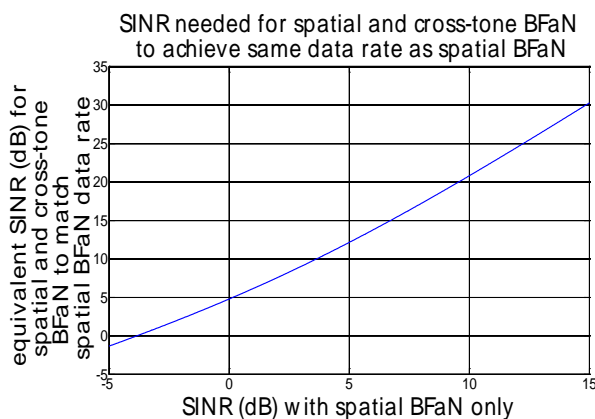


Fig. 3 SINR comparison with spatial BFaF and spatial and cross-tone BFaF

In general, a cell edge user first calculates its SINR using SU-MIMO ($SINR_1$), spatial BFaF ($SINR_2$), spatial and cross-tone BFaF ($SINR_3$) with the pilots embedded with signals or using the synchronization preamble. Next, it derives the data rate associated with the three schemes by looking up the corresponding MCS using the calculated SINR values. Finally, the edge MS request it's serving BS to employ the scheme that provides the highest potential data rate.

III. SIMULATION RESULTS

Link level simulation alone cannot accurately quantify the performance gain of an interference mitigation scheme. This is due to the fact that the actual interference present in the system is a function of the resource scheduling performed at each BS. Without the actual scheduling function, the actual interference environment cannot be captured and the performance gain cannot be measured. We implemented our SU-MIMO, spatial BFaF, spatial and cross-tone BFaF scheme in a system level simulator developed at Intel and are compliant to the IEEE 802.16m Evaluation Methodology Document [1]. System level simulations with a proportional

fair scheduler and full buffer traffic model at both the BSs and MSs are performed to investigate the system throughput improvement of our DARA scheme. To reduce cost and power consumption at MSs, it is assumed that each MS uses one transmit in the UL and two receive antennas in the DL. A summary of simulation parameters can be found in Table I.

TABLE I SIMULATION PARAMETERS SUMMARY

Parameters	Values
Cellular Layout	19 Cells/ 3 Sectors Per Cell with Wrap Around
Inter-site Distance	1500 Meters
Fading Channel	IEEE 802.16m ITU-PEDB and IEEE 802.16m ITU-VEHA
MS Speed	3kmh, 30kmh, 120kmh, 240kmh, 500kmh
Bandwidth	10mhz
Subcarrier Permutation	DPRU (Distributed Physical Resource Unit)
Number Of MS Per Sector	10
Subframe Duration	2.5ms
Antenna Configuration	4x2 (4 BSTx, 2 MS Rx) SU MIMO as Baseline, 4x2 for Our DARA Scheme

To highlight the performance gain of our DARA scheme, we compare the simulation result against the new baseline system. In this baseline system, 4×2 SU MIMO with various numbers of streams is used depending on the channel conditions. In simulating the baseline system, delayed perfect channel knowledge is assumed. This implies that BSs use perfect channel that exists 5ms ago to calculate the scheduling metrics and make scheduling decisions. When our DARA scheme is enabled, BSs will use 4×2 SU MIMO, DL transmit BFaF with or without cross-tone to communicate with the cell edge users using 4 BS antennas while cell center MSs are served using 4×2 SU MIMO only.

A. Simulation Results and Comparison at Low Mobility

A CDF of average MS throughput rate can be found in Figure 4.

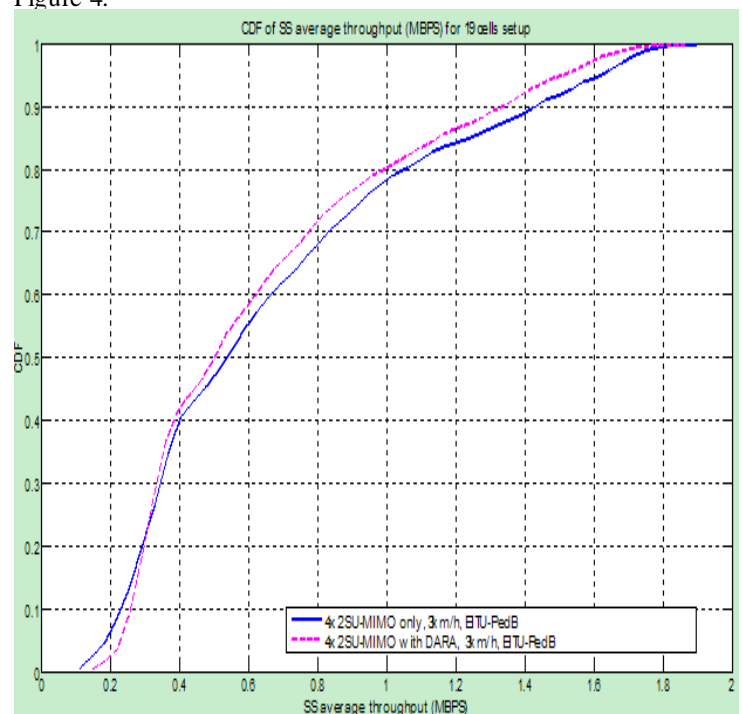


Fig. 4 CDF of average MS throughput rate of DARA and baseline

Cell edge user throughput rate is defined to be the throughput rate at 5% of the CDF curve. Average cell throughput rate is defined to be the throughput rate at 50% of the CDF curve. Our DARA scheme outperforms the baseline by 22.29% increase in the cell edge MS throughput while keeping the average cell throughput rate drop to be less than 5%. Hence, our design satisfies the performance requirement.

B. Simulation Results for Higher MS speeds

Feedback and computation delays of 5ms are introduced between the time when beamforming weights are calculated and when the beamforming weights are actually applied. This causes channel mismatch which increases with mobile speeds. From Figure 5, it is observed that the gain in cell edge MS

throughput rate drops as MS speed increases. However, the system degrades gracefully with increasing MS speed and our DARA scheme satisfies the system performance requirement most of the time. For cell edge MSs with higher speed, it seems like a multiplier of 1.2 should be used.

TABLE III SIMULATION RESULT FROM BASELINE AND DARA SCHEME

Mode/Performance	Average MS Throughput Increase Over Baseline in %	Cell Edge MS Throughput Increase Over Baseline in %
4x2, SU MIMO Baseline	0	0
4x2, DARA With Multiplier 1.4	-4.91	22.29

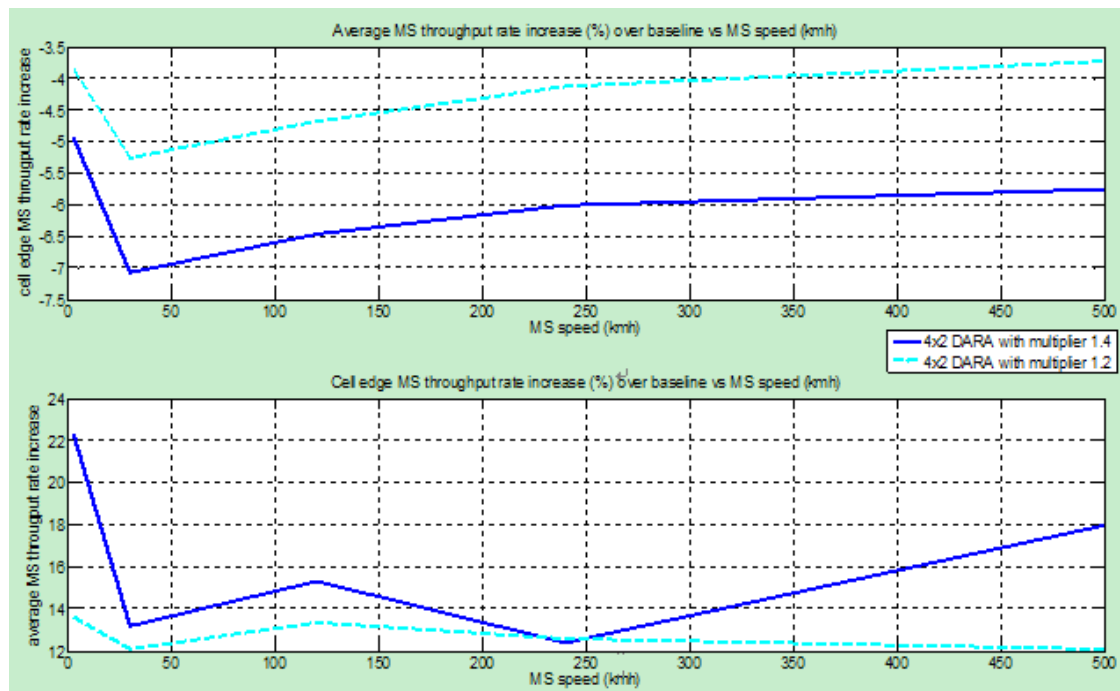


Fig. 5 Throughput rate increase of DARA over the baseline system with moving MSs

IV. CONCLUSIONS

The optimality and efficiency of our DARA scheme is proved and quantified by system level simulations. It increases the cell edge MS throughput rate compared to the baseline implementation even for high MS speed. Our scheme is simple to implement since it is already supported by the current 802.16e message exchange and sounding mechanisms.

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